Experimental Study On Partial Replacement Of Cement With Silica Fume In Hybrid Fibre Reinforced Concrete Using Carbon And Steel Fibres

Ms. Ahire Shweta Pradeep
[2, 3, 4, 5]Dept of Civil Engineering
School Of Engineering And Technology, Sandip University

Abstract- *Infrastructure development for a country is a principle development and concrete plays a vital role. Concrete is the world's largest consuming material in the field of construction. From time immemorial research over concrete has been going on to enhance its performance and strength. Nowadays, most concrete mixture contains supplementary cementious material (SCM) which forms part of the cementitious component. These materials are majority by-products from other processes. The main benefits of SCMs are their ability to replace certain amount of cement and still able to display cementitious property, thus reducing the cost of using Portland cement. The fast growth in industrialisation has resulted in tons and tons of by-product or waste materials, which can be used as SCMs such as silica fume, by adding steel fibers and carbon fibers etc. The use of these by-products not only helps to utilize these waste materials but also enhances the properties of concrete in fresh and hydrated states.*

This study focuses on the experimental investigation of partial replacement of cement with Ground Granulated Blast Furnace Slag (GGBS) in Hybrid Fibre Reinforced Concrete (HFRC) using steel and carbon fibres. The main objective is to evaluate the mechanical and durability properties of concrete with varying percentages of GGBS.

Cement is partially replaced with GGBS at different proportions such as 0%, 20%, 40%, and 60%. Hybrid fibres are added to improve tensile strength, crack resistance, and ductility. Steel fibres enhance load-carrying capacity, while carbon fibres help in controlling micro-cracks.

The experimental program includes tests on compressive strength, split tensile strength, and flexural strength. The results indicate that GGBS improves long-term strength and durability, while hybrid fibres significantly enhance mechanical performance. The study concludes that GGBS-based hybrid fibre reinforced concrete is a sustainable and high-performance construction material.

I. INTRODUCTION

General

In the present era very vast development occurred in the field of construction specially in concrete technology.

Field of concrete technology developments strive towards the achievement of higher and higher strength concrete.

Concrete is the most important engineering material and the addition of some other materials may change the properties of concrete.

Concrete is the most versatile material due to its continuous demand. Engineers are continuously pushing the limits to improve the performance with the help of supplementary cementitious material like blast furnace slagGGBS, Fly ash, steel slag, silica fume etc.

The present research work focused on one of such product . In this, we will study the effect of GGBS in the concrete properties with their different percentages with the addition of steel fibers and carbon fibers.

GGBS particles sizes are very very small so they can fill the pores or small spaces of concrete easily and effectively , it acts as filler and a cementious material.

Aim of study

As far as the rigid pavements are considered, their utilization is increasing day by day due to the vast field of applications; like harbours air strips, bus stands and other heavily traffic loaded areas. Various experiments have been done in this regard to increase the compressive as well as the Tensile strength of the pavement quality concrete.

This study is essential in the way so as to study the effective strength of concrete with the addition of Ground

Granulated Blast Furnace Slag (GGBS) with the introduction of steel fibres. Ground Granulated Blast Furnace Slag (GGBS) is known to increase the density and hence the compressive strength of concrete. On the other hand steel fibres intend to increase the flexural strength, this reduces the tension in the pavement concrete, and hence the cracks developed in the cracks under the heavy loading. Hence this study intends to solve the major problem of cracking in the concrete pavements as well as increasing the overall strength of concrete

Objectives of the study

To study variation of concrete strength with variation in Ground Granulated Blast Furnace Slag (GGBS) , steel fibers and carbons fibers

To obtain an optimum dosage of silica fume, steel fibres and carbon fibres up to which there will be significant increase in both the Compressive and Split tensile strength.

Compare the Compressive strength and Split tensile strength of various mixes with varying % of Ground Granulated Blast Furnace Slag (GGBS) , Steel fibres and carbon fibres with Nominal mix

II. LITERATURE REVIEW

2.1 Recent studies

Various Literature review on topic related to replacement of cement by Ground Granulated Blast Furnace Slag (GGBS) with fibers is studied and suggested that 10% can be attributed as the optimum dosage of silica fume that can be added as a partial replacement of cement for maximum compressive strength. As soon as the fibres were increased up to 1.2%, 1.4%, there was a decrease in the flexural strength of the beams. So with Ground Granulated Blast Furnace Slag (GGBS) as partial replacement of cement, 1% steel fibre was optimum percentage for maximum flexural strength.

Verma et al. (2024)

Verma et al. conducted an experimental study on Hybrid Fibre Reinforced Concrete incorporating GGBS as a partial replacement of cement. The study revealed that the use of GGBS (up to 40–50%) significantly enhances compressive strength, split tensile strength, and flexural strength at later ages. The inclusion of hybrid fibres (steel and carbon) improved crack resistance and ductility. It was also concluded that such concrete is more sustainable due to reduced cement consumption and lower carbon emissions.

Reddy et al. (2023)

Reddy et al. investigated the mechanical properties of concrete with GGBS and steel fibres. The results indicated that GGBS improves workability and long-term strength, while steel fibres contribute to better load-carrying capacity and resistance to cracking. The combination resulted in improved compressive strength and tensile strength compared to conventional concrete.

Singh & Kaur (2022)

The researchers studied hybrid fibre reinforced concrete using different proportions of fibres along with GGBS. The study showed that hybrid fibres significantly improve toughness, energy absorption capacity, and resistance to crack propagation. GGBS contributed to improved durability and reduced permeability, making the concrete suitable for aggressive environments.

Zhang et al. (2021)

Zhang et al. focused on carbon fibre reinforced concrete and its durability aspects. The study found that carbon fibres enhance resistance to corrosion and micro-cracking. When combined with GGBS, the concrete exhibited improved microstructure, leading to higher durability and longer service life.

Patel et al. (2020)

Patel et al. evaluated the effect of GGBS on strength characteristics of fibre reinforced concrete. The study concluded that an optimum replacement level of around 40% GGBS yields the best results in terms of compressive and flexural strength. Beyond this percentage, strength gain slows down.

Kumar & Sharma (2019)

This study analyzed the behavior of fibre reinforced concrete using steel and carbon fibres. Steel fibres were found to improve impact resistance and load-bearing capacity, whereas carbon fibres were effective in controlling micro-cracks. The hybrid combination provided superior performance compared to single fibre concrete.

Siddique (2018)

Siddique emphasized the benefits of using industrial by-products like GGBS in concrete. The study highlighted improved workability, reduced heat of hydration, and enhanced durability. It also promoted sustainable construction practices by reducing cement usage.

Rao et al. (2016)

Rao et al. studied hybrid fibre reinforced concrete and concluded that the use of multiple fibres improves tensile strength, ductility, and resistance to cracking. The hybrid approach was found to be more effective than using a single type of fibre.

Mehta & Monteiro (2014)

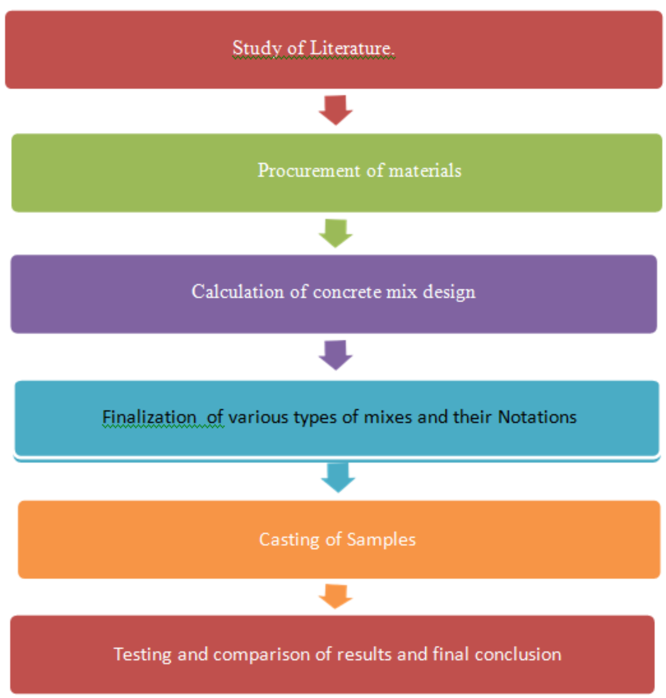
Their research highlighted the role of GGBS as a supplementary cementitious material. It improves resistance to sulfate attack, reduces permeability, and enhances long-term strength development of concrete.

Neville (2011)

Neville explained that GGBS contributes to the formation of a denser concrete matrix, reducing porosity and increasing durability. It is particularly beneficial in improving resistance to environmental effects.

III. METHODOLOGY

3.1 FlowChart of Project



3.2 Detailed Methodology

In Hybrid Fibre Reinforced Concrete (HFRC), steel fibres and carbon fibres are uniformly distributed throughout the concrete matrix. Proper mixing ensures that fibres are randomly oriented and present at all depths, which results in uniform strength in all directions. This enhances the overall mechanical properties such as tensile strength, ductility, and crack resistance of concrete.

For the mix procedure, dry ingredients such as coarse aggregates, fine aggregates, cement, and Ground Granulated Blast Furnace Slag (GGBS) were mixed in a concrete mixer for about 45 seconds. After proper dry mixing, steel fibres and carbon fibres were added gradually to ensure uniform distribution. Superplasticizer was then added to improve workability.

Water was added slowly while the mixing process continued until a homogeneous and uniform mix was obtained. Care was taken to ensure that fibres were evenly distributed throughout the concrete without forming lumps or segregation.

Fig 3.1: Concrete cubes to be cast in the mould

For this study, concrete cubes of size 150 mm × 150 mm × 150 mm were cast to determine compressive strength at 7 and 28 days. Different mixes were prepared with varying percentages of GGBS such as 0%, 20%, 40%, and 60% replacement of cement.

Control specimens without GGBS and fibres were also cast to compare the results. For each mix, three specimens were cast and the average value was considered for accuracy.

The experimental program involved trial mixes to determine the optimum percentage of GGBS and fibre content. The specimens were demoulded after 24 hours and cured in water for 7 and 28 days before testing.

3.3 Materials

3.3.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a by-product obtained from the iron manufacturing industry. It is produced by quenching molten iron slag from a blast furnace in water, resulting in a glassy granular material which is then ground into a fine powder.

GGBS is used as a partial replacement for cement due to its pozzolanic properties. It improves durability, reduces heat of hydration, and enhances long-term strength.

Properties of GGBS

a) Physical Properties:

- Color: Off-white
- Fineness: Similar to cement
- Specific Gravity: 2.85–2.95

b) Chemical Properties:

- Calcium Oxide (CaO): 30–45%
- Silica (SiO_2): 30–40%
- Alumina (Al_2O_3): 10–15%

Working Mechanism of GGBS in Concrete

GGBS works based on the pozzolanic reaction. When water is added to cement, hydration produces Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide ($Ca(OH)_2$).

Cement + Water → C-S-H + $Ca(OH)_2$

GGBS reacts with calcium hydroxide in the presence of water to form additional C-S-H gel:

$Ca(OH)_2$ + GGBS → Additional C-S-H

This reaction improves strength, reduces permeability, and enhances durability. It also reduces harmful effects like sulphate attack and alkali reactions.

Fig 3.2: Production of GGBS

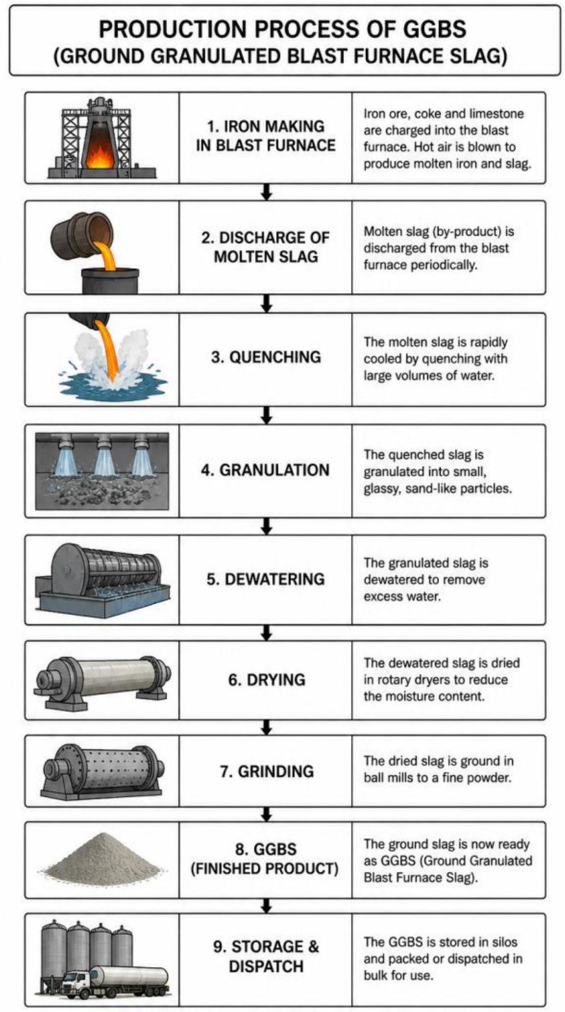


Fig 3.X: Flow Chart of Production Process of GGBS

Cement

The most widely used of the construction cements is Portland cement. It is a bluish gray powder obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw material is a mixture of high-calcium limestone, known as cement rock, and clay or shale

The cement used was taken from a local JAYPEE CEMENT Vendor and the cement used is OPC with , Initial setting time of 48 min and final setting time of 283 min with a specific gravity of 3.15.

The cement has been checked for various properties and they have been accurately taken keeping in mind the limits specified by IS: 8112-1989

3.3.3 Fine aggregate

The fine aggregate ispassing through 4.75mm sieve and had a specific gravity of 2.72**.**

3.3.4 Coarseaggregate

For coarseaggregate, the maximumsize of aggregatein between 20mmzto 4.75mm. The physicalproperties of bothfine aggregate andcoarse aggregatezareevaluatedzas per

IS: 2386z(Part III)-1963 and givenzin Table and fine aggregate river sand bought from a local vendor from the same place with fineness modulus 2.389 confirming to Zone III.

Table 3.1. Properties of Aggregate

S No	Property	Coarse aggregate
1	Specific Gravity	2.72
2	Bulk Density (kg/L)	1.408
3	Loose Bulk Density (kg/L)	1.25
4	Water Absorption (%)	4.469
5	Impact Value	26.910
6	Crushing Value	26.514
7	Fineness Modulus	3.38

3.3.5 Water

In general water that is fit for drinking is considered fit for making concrete. Water should be free from acids, oils, alkalis, vegetables or other organic impurities. Soft water also produces weaker concrete.

Generally water used and suitable for concrete is tap portable water

3.3.6.1 Steel Fibre

The steel fibers are mostly used fiber for fiber reinforced concrete out of available fibers in market. According to many researchers, the addition of steel fiber into concrete creates low workable or inadequate workability to the concrete, therefore to solve this problem of Super plasticizer without affecting other properties of concrete may introduce.

Steel fibers are made of shredded steel wire having low percentage of carbon (C) or also known a stainless steel mesh. The fibers can be flat, hooked or undulated. Undulated steel fibers are effective in a way that the concrete holds a better grip over the surface of the fibers.

Undulated steel fibres were used in this research.

SR NO	PROPERTIES	VALUES
1	Diameter	0.05-0.3mm
2	Length	5-40mm
2	Ultimate Strength	400-500MP
3	Elastic Modulus	200-210GP
4	Density	7850kg/m3

Fig 3.3: Steel Fibers

3.3.7 Carbon Fibre

The short carbon fibres were pitch-based and unsized. Variousnominal fibre lengths (provided by the fibre manufacturer) from 3.0 to 12.7mm were used.Unless stated o otherwise, fibres of nominal length 5.1mm were used.The technique of dispersing carbon fibres randomly in the concrete mixis critical tothe success of the carbon fibre reinforced concrete technology. Two options arepossible. One is to mix the fibres with cement and fine aggregate in the dry state (referred to as"Dry Mix" in this paper). The other option is to first disperse the fibres in water and then pour the dispersion into the slurry with cement and fine aggregate (referred to as"Wet Mix" in this paper). The second option is much more practical.

Carbon Fibers are produce by bonding carbon atoms together in crystals that are aligned parallel to the axis of Fiber. Carbon Fibers have been manufactured with petroleum and coal pitch with 5-10 micrometer in diameter with specific gravity near about 1.9. The crystal alignment gives the Fiber high strength to volume ratio and the modulus of elasticity is higher than steel and it is twice or thrice stronger than steel. They have high stiffness, high chemical resistance, high temperature tolerance and low thermal expansion.

Fig 3.4: Carbon Fibre.

3.4 Mix design of concrete of river sand as fine aggregate:

There are various methods of mix design. In the present work, Indian Standard method (IS: 10262 - 2009) is used for Concrete mix design of grade M25

3.4.1 Mix design of grade M25

I] Stipulations for proportioning:

a) Grade designation: M25
b) Type of cement: OPC 53 grade confirming to IS 8112
c) Maximum nominal size of aggregate: 20mm
d) Minimum cement content: 30 kg/m^2
e) Maximum water-cement ratio: 0.45
f) Workability: 100 mm (slump)
g) Type of aggregate: Crushed angular aggregate
h) Chemical admixture type: Super plasticizer

II] Test data for materials:

a) Cement used: OPC 43 grade confirming to IS 8112
b) Specific gravity of cement: 3.15
c) Specific gravity of coarse aggregate: 2.74
d) Specific gravity of Fine aggregate: 2.63
e) Water absorption of coarse aggregate: 1.02%
f) Water absorption of fine aggregate: 1.0%

Procedure for Concrete Mix Design of Concrete

A) Target Strength from mix proportioning:

Himsworth constant for 5% risk factor is 1.65. In this case standard deviation is taken from IS: 456 against M 25 are 4.0.

$$f'ck = fck + 1.65S$$

Where,

f'ck = target average compressive strength at 28 days,
Fck = characteristic compressive strength at 28 days and
s = Standard deviation
(From Table 1 of IS 10262:2009, Standard Deviation, s = 4 N/mm^2)
Target strength = $f'ck$= 20 + 1.65×4 = 26.60 N/mm^2

B) Selection of water-cement ratio:

From Table 5 of IS 456(Page No-20),
Maximum water-cement ratio = 0.45
Based on experience, adopt water-cement ratio as 0.45,
0.40 < 0.45, Hence O.K.

C) Selection of water content:

From Table 2, maximum water content for 20mm aggregate = 186 liter
Estimated water content for 100 mm slumps = 186 + 6100 x 186 = 197 liter's
As super plasticizer is used, the water content can be reduced up to 20 percent.
Based on trials with super plasticizer water content reduction of 29% has been achieved. Hence, the arrived water content = 197 x 0.71 = 140 liters.

D) Calculation of cement content:

Water cement ratio	: 0.45
Cementious material (cement + SCM) content	: 175.5/0.45 = 390kg/m^3
From table 5 of IS 456, minimum cement content for 'severe' exposure conditions	: 320 kg/m^3

E) Proportion of volume of coarse aggregate and fine aggregate content:

From Table 3 of IS 10262:2009, volume of coarse aggregate corresponding to 20 mm size aggregate for water cement ratio of 0.50=0.60

In the present case water cement ratio is 0.45. Therefore, volume of coarse aggregate is required to be increased to decrease the fine aggregate content. As the water cement ratio is lower by 0.10, the proportion of volume of coarse aggregate is increased by 0.02 (at the rate of ± 0.01 for every ± 0.05 change in water cement ratio). Therefore, corrected proportion of volume of coarse aggregate for the water-cement ratio of 0.40 = 0.62

Therefore, volume of coarse agg. = 0.62×0.9 = 0.56

Volume of fine agg. = 1- 0.56 = 0.44

F) Mix Calculations:

The mix calculations per unit volume of concrete shall be as follows:

a).Volume of concrete = 1 m^3

b).Volume of cement = $Mass of cement/Specific gravity of cement$ x 1/1000

= 311.123.15 x 1/1000

= 0.0987 m^3

c).Volume of water = $Mass of water/Specific gravity of water$ x 1/1000

= 1401 x 1/1000

= 0.140 m^3

d) Volume of chemical admixture

(Super plasticizer)@ 2% by mass = $Mass of admixture/Sp. gravity of admixture$ X 1/1000

Of cementious material

= 71.145 x 1/1000 == 0.006m^3

e)Volume of all in aggregate = [a – (b + c + d)]

= 1 – (0.0987 + 0.140 + 0.006)

= 0.75 m^3

f) Mass of coarse aggregate = e x vol. of C.A x specific gravity of C.A ×1000

= 0.75 x 0.56 x 2.74 x 1000

= 1150 kg

g) Mass of fine aggregate = e x vol. of F.A x specific gravity of F.A × 1000

= 0.75 x 0.44 x 2.63 x 1000

= 868 kg

III] Mix proportions:

Cement = 311.12 kg/m^3

Water = 140 kg/m^3

Fine aggregate = 868 kg/m^3

Coarse aggregate = 1150 kg/m^3

Water-cement ratio = 0.45

Table 3.2 Quantity of material per cubic meter of concrete (M25)

Material	**Proportion by weight**	**Weight in kg/m^3**
Cement	1	311.12
F.A	2.79	868
C.A	3.70	1150
W/C	0.45	140 lit

Table 3.3 Quantity of material per 50 kg of cement (M20)

Material	**Proportion by weight**	**Weight in kg/m^3**
Cement	1	50
F.A	2.79	140
C.A	3.70	185
W/C	0.45	22.5
Steel Fiber	10%	5

3.4.2 EXPERIMENTAL SETUP

For studying the compressive strength cubic samples with dimensions 150*150*150 mm were used. They were tested by loading after 7 and 28 day's. The load was applied perpendicular to the upper face of cube, and the loading speed of the compressive testing machine was 5 mm/min. The apparatus used to test had a loading capacity of about 3000KN Three specimens each were casted for each mix design for 7 and 28 days of testing.

For this research, 30 cubes each with dimensions 150x 150 x 150mm were casted to test the compressive strength with varying steel fibre, carbon fibre and Ground Granulated Blast Furnace Slag (GGBS) percentage after 7 and 28day's . This experiment required lot of trial work needed to find out the maximum strength at optimum quantity of steel fibres, carbon fibres as well as optimal percentage of Ground Granulated Blast Furnace Slag (GGBS). In order to determine that, the optimum quantity of steel fibres and carbon fibres is tested against different percentages of Ground Granulated Blast Furnace Slag (GGBS).

NOTATION'S

Sr.No	Material	Notation
1	Ground Granulated Blast Furnace Slag (GGBS)	A
2	Steel Fibers	B
3	Silica fibers	C

Sr.No	Notation	Composition Of Mix	Types of Specimen
1	M1	M25	M25 Standard Cube/Cylinder
2	M2	10% A1	GGBS Cube/ Cylinder
3	M3	20% A2	
4	M4	30% A3	
5	M5	A 10% + 0.9% B1	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's (SF 10% + ST F)
6	M6	A 10% + 1% B2	
7	M7	A 10% + 1.2% B3	
8	M8	A 10% + 0.9% C1	Ground Granulated Blast Furnace Slag (GGBS) + Carbon Fiber's (SF 10% + C. F)
9	M9	A 10% + 1% C2	
10	M10	A 10% + 1.2% C3	
11	M11	A10% + 1% B + 1% C	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's+Carbon Fiber's (SF 10% + ST F 1% + CF 1%)

3.4.2.1 Compressive Strength Test:

To determine the precise compressive strength of cubes an average of three samples were taken for every reading. The testing of specimens has been performed after curing period of 7 and 28 days for both controlled as well as for cubes with partial replacement of cement with Fine aggregates and Course aggregate with the addition of steel fibres and carbon fibres.

3.4.2.2 Split Tensile Strength

The tensilezstrength of concreteis one of thebasic and importantproperties. Splitting tensilezstrength teston concretecylinder is amethod todetermine thetensile strength ofconcrete. Theconcrete isvery weak in tension dueto its brittlenature and is notzexpected toresist thedirect tension. Theconcrete developscracks whensubjected to tensileforces. Thus, itzis necessary todetermine thetensile strengthof concrete to determinethe load at whichthe concretemembers maycrack. To determinethe split tensileof concrete.

3.5 Schedule of Casting

Table 3.5 Casting details ofcube

Sr.No	Type of Specimen		No. of Specimen	No. of Specimen
	M25 Standard Cube	M1	3	3
1	Silica fume Cube	M2	3	3
2		M3	3	3
3		M4	3	3
4	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's (SF 10% + ST F)	M5	3	3
5		M6	3	3
6		M7	3	3
7	Ground Granulated Blast Furnace Slag (GGBS) + Carbon Fiber's (SF 10% + C. F)	M8	3	3
8		M9	3	3
9		M10	3	3
Total no of specimen			30	30

Table 3.5 Casting details of Cylinder

SR NO	Type of Specimen		No of Specimen
	M20 Standard Cylinder	M1	3
1	Ground Granulated Blast Furnace Slag (GGBS) Cylinder	M2	3
2		M3	3
3		M4	3
4	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's (SF 10% + ST F)	M5	3
5		M6	3
6		M7	3
7	Ground Granulated Blast Furnace Slag (GGBS) + Carbon Fiber's (SF 10% + C. F)	M8	3
8		M9	3
9		M10	3
		Total	30

Table 3.5 Casting details of Cylinder

Table 3.6 Casting details of Cube

SR NO	Type of Specimen	Notation's	No if Specimen for 7 days	No if Specimen for 28 days
1	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's+Carbon Fiber's (SF 10% + ST F 1% + CF 1%)	M11	3	**3**

Table 3.7 Casting details of Cylinder

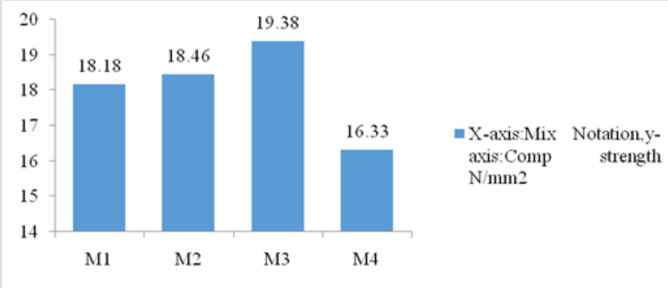
SR NO	Type of Specimen	Notation's	No if Specimen
1	Ground Granulated Blast Furnace Slag (GGBS) + Steel Fiber's+Carbon Fiber's (SF 10% + ST F 1% + CF 1%)	M11	3

II. RESULTS AND DISCUSSION

The results obtained by carrying out the tests on the cubes and cylinders made with mix proportions decided earlier are as stated below by consider the various percentage

Table 4.1: Variation of Compression strength with variation of Ground Granulated Blast Furnace Slag (GGBS) %at the end of 7days

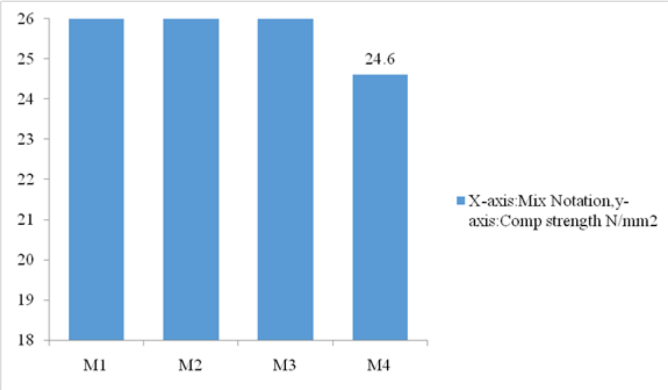
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	17.78	18.18
			18.18	
			18.38	
		M2	18.68	18.46
			18.88	
			18.90	
		M3	19.22	19.38
			19.40	
			19.95	
		M4	16.22	16.33



Graph 4.1: Variation of Compression strength with variation of Ground Granulated Blast Furnace Slag (GGBS) %at the end of 7days

Table 4.2 :Variation of Compression strength with variation of Ground Granulated Blast Furnace Slag (GGBS) %at the end of 28days

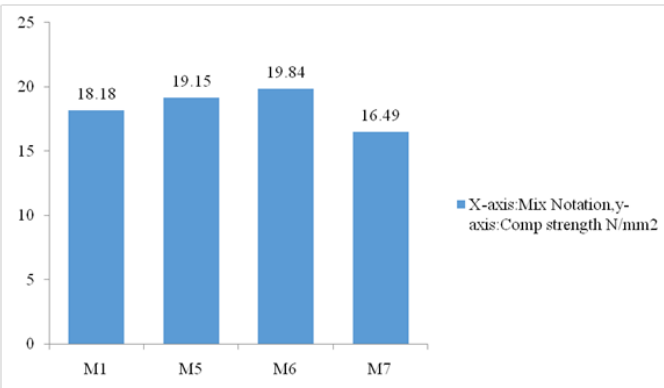
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	26.60	26.41
			25.70	
			26.65	
		M2	26.40	26.6
			26.50	
			26.90	
		M3	27.60	27.65
			26.45	
			27.80	
		M4	24.30	24.60
			24.90	
			24.60	



Graph 4.2: Variation of Compression strength with variation of Ground Granulated Blast Furnace Slag (GGBS) %at the end of 28days

Table 4.3: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs varation of steel fiber %.at the end of 7days

Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	17.78	18.18
			18.18	
			18.38	
		M5	18.68	19.15
			19.87	
			18.90	
		M6	19.52	19.84
			19.90	
			20.10	
		M7	16.22	16.49
			16.53	
			16.73	



Graphs 4.3: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of steel fiber %.at the end of 7days

Table 4.4:Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of steel fiber %.at the end of 28days

Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	25.60	26.41
			25.70	
			26.65	
		M5	27.40	27.61
			27.54	
			27.90	
		M6	28.63	28.33
			27.55	
			28.83	
		M7	25.30	25.60
			25.90	
			25.60	

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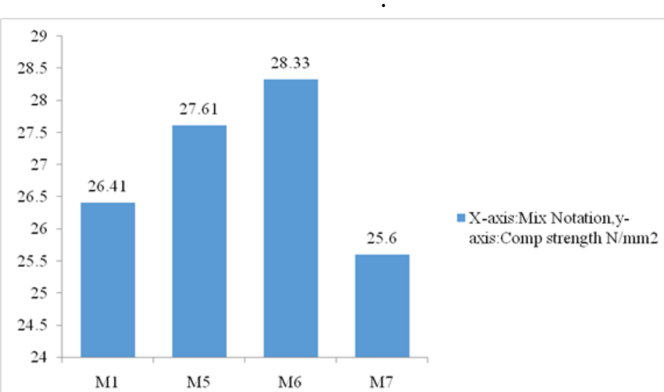
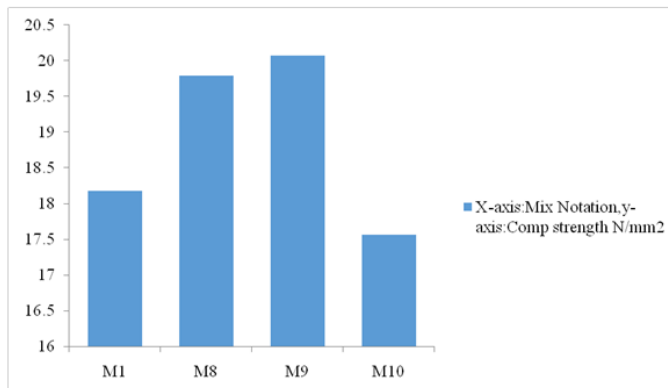


Graphs 4.4: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs. variation of steel fiber %.at the end of 28days

Table 4.5:Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs. variation of carbon fiber %.at the end of 7days

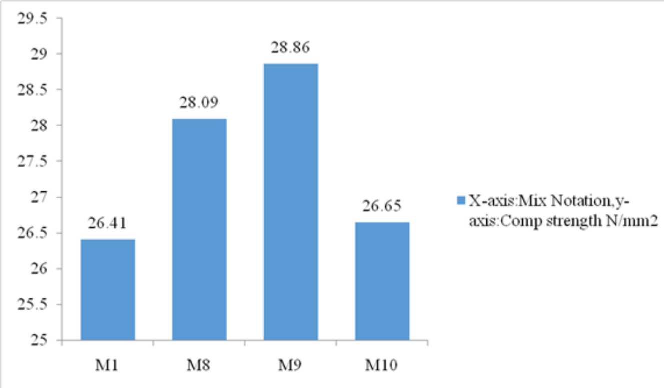
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	17.78	18.18
			18.18	
			18.38	
		M8	19.80	19.79
			19.67	
			19.90	
		M9	19.92	20.07
			20.10	
			20.20	
		M10	17.33	17.56
			17.63	
			17.73	



Graphs 4.5: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs. variation of carbon fiber %.at the end of 7days

Table 4.6: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs. variation of carbon fiber %.at the end of 28days

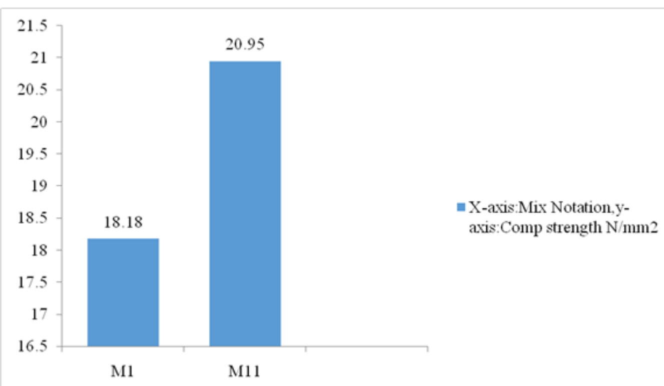
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M1	25.60	26.41
			25.70	
			26.65	
		M8	27.63	28.09
			28.54	
			28.10	
		M9	28.90	28.86
			28.73	
			29.03	
		M10	26.36	26.65
			26.92	
			26.68	



Graphs 4.6: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs. variation of carbon fiber %.at the end of 28days

Table 4.7: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 7days

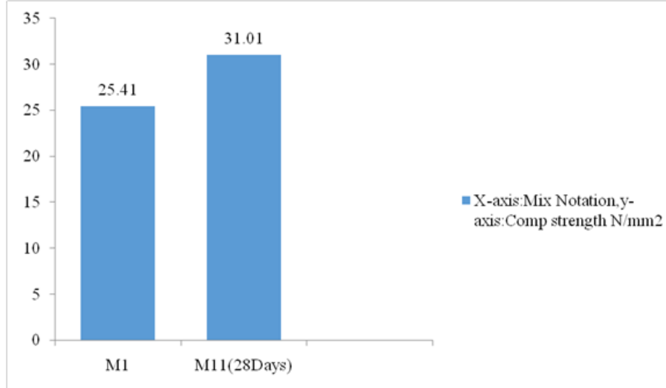
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M11	19.90	20.95
			21.10	
			20.86	



Graph 4.7: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 7days

Table 4.8: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 28days

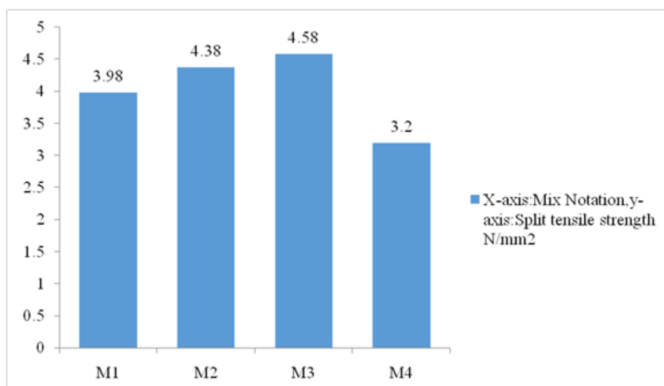
Grade of Concrete	w/c Ratio	Notation's	Compression Strength in N/mm^2	Average Compression Strength in N/mm^2
M25	0.45	M11	30.86	31.01
			31.23	
			30.94	



Graphs 4.8: Variation of Compression strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 28days

Table 4.9:Variation of Split tensile strength with variation of Ground Granulated Blast Furnace Slag (GGBS) % at the end of 28days

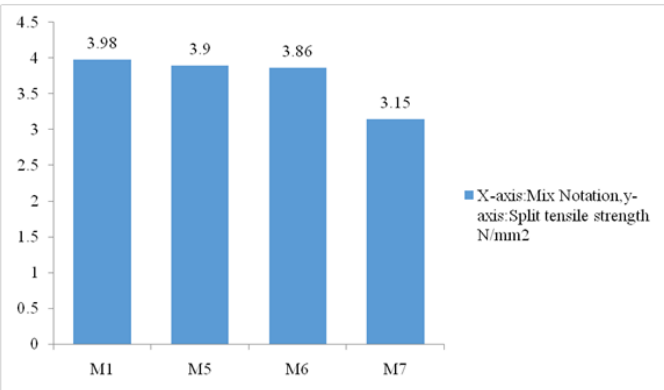
Grade of Concrete	w/c Ratio	Notation's	Split tensile Strength in N/mm^2	Average Split tensile Strength in N/mm^2
M25	0.45	M1	3.45	3.98
			4.38	
			3.98	
		M2	4.38	4.38
			4.23	
			4.53	
		M3	4.98	4.58
			4.55	
			4.55	
		M4	3.20	3.20
			3.55	
			3.18	



Graph 4.9: Variation of Split tensile strength with variation of Ground Granulated Blast Furnace Slag (GGBS) % at the end of 28days

Table 4.10: Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of steel fibers % at the end of 28days

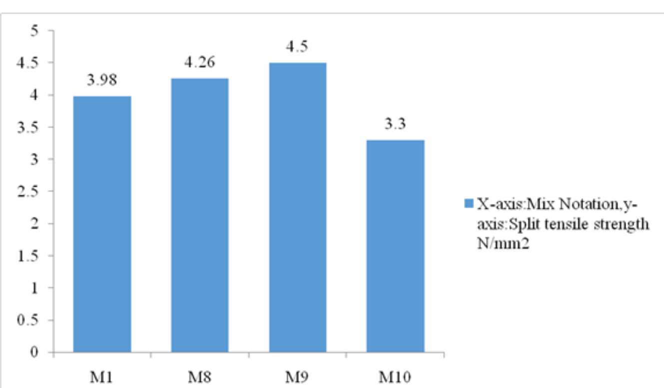
Grade of Concrete	w/c Ratio	Notation's	Split tensile Strength in N/mm^2	Average Split tensile Strength in N/mm^2
M25	0.45	M1	3.45	3.98
			4.38	
			3.98	
		M5	3.80	3.90
			4.13	
			3.95	
		M6	3.98	3.86
			4.20	
			3.85	
		M7	3.15	3.15
			3.35	
			3.10	



Graph 4.10: Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of steel fibers % at the end of 28days

Table 4.11: Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of Carbon fibers % at the end of 28days

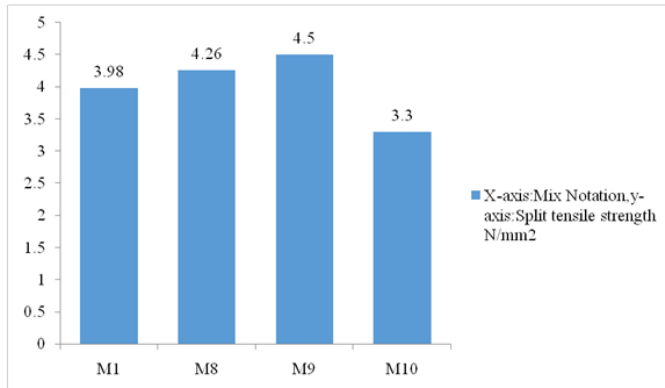
Grade of Concrete	w/c Ratio	Notation's	Split tensile Strength in N/mm^2	Average Split tensile Strength in N/mm^2
M25	0.45	M1	3.45	3.98
			4.38	
			3.98	
		M8	4.23	4.26
			4.42	
			4.15	
		M9	4.38	4.5
			4.63	
			4.65	
		M10	3.32	3.30
			3.45	
			3.18	



Graph 4.11: Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) %(10%) vs variation of Carbon fibers % at the end of 28days

Table 4.12: Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 28days

Grade of Concrete	w/c Ratio	Notation's	Split tensile Strength in N/mm^2	Average Split tensile Strength in N/mm^2
M25	0.45	M11	4.38	4.75
			4.90	
			4.98	



Graph 4.12 Variation of Split tensile strength with fixed Ground Granulated Blast Furnace Slag (GGBS) % (10%) + Carbon fiber% (1%) + Steel fibre% (1%) at the end of 28days

Comparative study of various optimum mixes-

To compare the result of various mixes with various additive fibers in a concrete i.e. silica fume, steel fibres and carbon fibres up to which there will be significant increase in both the Compressive and Split tensile strength

GRAPH 4.13 & 4.14 shows the comparitive result of all optimum mixes for both compressive and tensile strength

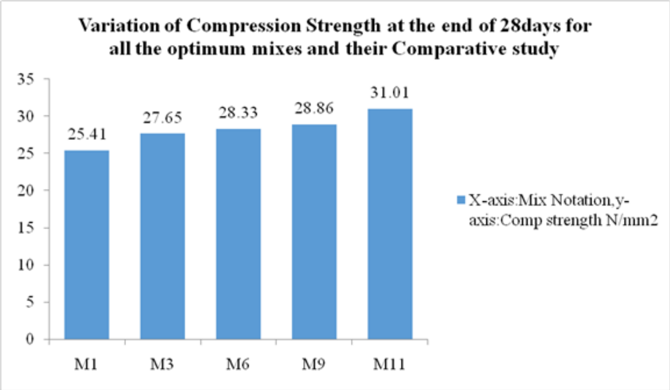
1)M1-Standard M25 mix

2) M3-30%Ground Granulated Blast Furnace Slag (GGBS)

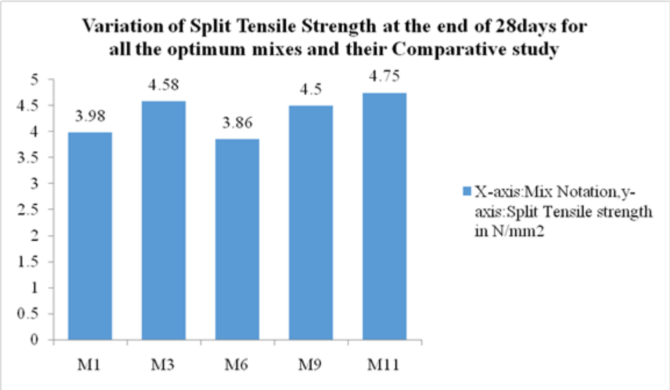
3) M6-1%Steel fibers with 10%Ground Granulated Blast Furnace Slag (GGBS)

4) M9-1%Carbon fibers with 10%Ground Granulated Blast Furnace Slag (GGBS)

5) M11- Combined Fibers(M3+M6+M9) i.e. (SF 10% + ST F 1% + CF 1%))



Graph 4.13: Variation of Compression Strength at the end of 28days for all the optimum mixes and their Comparative study



Graph 4.14: Variation of Split Tensile at the end of 28days for all the optimum mixes and their Comparative study

III. CONCLUSION

In this experimental investigation, the behaviour of hybrid fibre reinforced concrete with partial replacement of cement by Ground Granulated Blast Furnace Slag (GGBS) has been studied. The results obtained from the experimental work indicate that the use of GGBS along with steel and carbon fibres significantly improves the performance of concrete.

It was observed that with increase in percentage of GGBS, the workability of concrete improves due to its finer particle size and better lubrication effect. The compressive strength of concrete increases gradually up to an optimum replacement level and then shows a slight reduction at higher percentages. The mix with 10% and 20% GGBS showed moderate improvement in strength (about 3–12%), whereas the mix with 30% GGBS exhibited maximum strength gain of approximately 15–20%, making it the optimum replacement level.

Beyond this level, i.e., at 40% replacement, the rate of strength gain reduces and early strength is comparatively lower, although long-term strength is still satisfactory. The inclusion of hybrid fibres (steel and carbon fibres) has significantly enhanced the tensile strength, ductility, and crack resistance of concrete. The fibres help in controlling both micro and macro cracks, thereby improving the overall durability and structural performance.

Additionally, the use of GGBS reduces permeability and improves resistance against chemical attacks, making the concrete more durable in aggressive environmental conditions. From an environmental point of view, partial replacement of cement with GGBS contributes to reduction in carbon emissions and promotes sustainable construction.

Hence, it can be concluded that 30% replacement of cement with GGBS along with hybrid fibre reinforcement provides optimum results in terms of strength, durability, and overall performance of concrete.

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